Renewable and Sustainable Energy Reviews 14 (2010) 2214–2220

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Analysis of the assessment factors for renewable energy dissemination program evaluation using fuzzy AHP

Eunnyeong Heo [a,1], Jinsoo Kim [a,*], Kyung-Jin Boo [b,2]

[a] Department of Energy Systems Engineering, Seoul National University, 599 Gwanak-ro, Gwanak-gu, Seoul 151-744, Republic of Korea
[b] Division of New & Renewable Energy, Korea Energy Economics Institute, 665-1 Naeson 2-dong, Uiwang-si, Kyonggi-do 437-713, Republic of Korea

ARTICLE INFO

Article history:
Received 15 December 2009
Accepted 26 January 2010

Keywords:
Renewable energy
Criteria
Factors
Dissemination program
Fuzzy AHP

ABSTRACT

By 2030, Korean government aims to increase the share of new and renewable energy sources to 11% in the overall primary energy mix, that is, approximately 33 million TOE. However, carefully designed program is needed given the current low level of the share (2.37%, approximately 5.6 million TOE, as of 2007). Therefore, alongside R&D on new and renewable energy technology, establishing an effective dissemination program is also essential. This would require a decision-making base, for which this study established the criteria and factors and assessed the importance of each factor using the fuzzy analytical hierarchy process (AHP) method. Five criteria – technological, market-related, economic, environmental, and policy-related – and a total of seventeen factors were established. From the weights estimation results, we derived four major conclusions regarding the importance of economic feasibility, the advancement of the target technology in the global market, the disagreement between the policy maker and the specialist group, and the application of the results.

Contents

1. Introduction

Although the energy crisis has slightly abated in recent times, the possibility of a crisis caused by extremely high oil prices is still imminent. Simultaneously, the environmental crisis represented by climate changes is also a major problem in need of a solution. Furthermore, the economic development and population growth of developing countries such as the BRICs are expected to result in a steady increase in global energy demand. Consequently, the energy prices are also expected to rise. For these reasons, new and

* Corresponding author. Tel.: +82 2 880 8705; fax: +82 2 882 2109.
E-mail addresses: heoe@snu.ac.kr (E. Heo), jinsookim@snu.ac.kr (J. Kim), kjboo@keei.re.kr (K.-J. Boo).
[1] Tel.: +82 2 880 8323; fax: +82 2 882 2109.
[2] Tel.: +82 31 420 2139; fax: +82 31 420 2164.

1364-0321/$ – see front matter
doi:10.1016/j.rser.2010.01.020

renewable energy (NRE) is critical to mitigate the energy and environmental crisis. According to the World Energy Outlook 2008, modern renewable technologies grow extremely rapidly, and soon after 2010, they will overtake gas to become one of the largest sources of electricity, second only to coal [1].

The Republic of Korea is ninth on the list of primary energy-consuming countries in the world [2], and by 2013, it is expected to be part of the group of nations requiring mandatory reduction of greenhouse gas emissions. Therefore, the energy and environmental crisis is very serious problem in Korea. In 1987, Korea had established the Promotional Law of Alternative Energy Development because of the high degree of energy dependency overseas (over 96.6% in 2007). However, the law did not have the desired effect. After four revisions, the Promotional Law of New and Renewable Energy Development, Utilization and Dissemination was established in 2007, and the 3rd Basic Plan for New and Renewable Energy Technology Development, Utilization and Dissemination (hereafter known as the 3rd Basic Plan) was established in 2008 in order to mitigate the energy and environmental risks.

According to the 3rd Basic Plan, by 2030, the Korean government aims to increase the share of NRE sources in the overall primary energy mix to 11%, that is, approximately 33 million TOE. However, this is not an easy goal given the current level of the share (2.37%, approximately 5.6 million TOE, in 2007) [3]. Therefore, alongside R&D on NRE technology, the establishment of an effective dissemination program is also essential.

In order to establish a base for decision-making regarding an effective dissemination program, this study established the criteria and factors and assessed the importance of each factor. There has been sustained research on decision-making for NRE planning. Beccali et al. [4] focused on creating renewable energy diffusion strategies using the ELECTRE methods family and the application of the fuzzy set theory. They also analyzed the advantages and drawbacks of both methods. Xiaohua and Zhenmin [5] introduced the index system for appraising the sustainable development of rural energy and calculated the weighting of each index using the analytic hierarchy process (AHP). Aras et al. [6] used the AHP to determine the most convenient location for the construction of a wind observation station on campus. Nigim et al. [7] applied both the AHP and sequential interactive model for urban sustainability to assist communities in a pre-feasibility ranking of alternative local renewable energy sources. Pohekar and Ramachandran [8] reviewed and classified more than 90 papers that used multi-criteria decision-making (MCDM) techniques in the field of sustainable energy planning. Erdoğmuş et al. [9] evaluated the most suitable fuel for residential heating using the analytic network process with group decision-making. Løken [10] reviewed MCDM analysis methods for energy planning problems, particularly in the evaluation of alternative electricity supply strategies. Løken placed these methods into three main categories: value measurement models such as the multi-attribute theory; goal, aspiration, and reference level models such as goal programming; and outranking models such as ELECTRE and PROMETHE.

Recently, Jaber et al. [11] evaluated space heating systems running on conventional and renewable energy sources in Jordan using fuzzy sets and the AHP. Analyses using both methods showed that heating systems based on renewable energy are most favorable. Arán Carrión et al. [12] described the environmental decision-support system based on the AHP for selecting optimal sites for grid-connected photovoltaic power plants. Their research took into account criteria related to the environment, orography, location, and climate. Mirza et al. [13] identified and classified six barriers that limit the use of renewable energy technologies—policy and regulatory, institutional, fiscal and financial, market-related, technological, and informational and social. Lee et al. [14] proposed an MCDM model based on the AHP associated with benefits, opportunities, costs, and risk merits to help select a suitable wind farm project. Terrados et al. [15] investigated energy planning models and proposed a hybrid methodology based on a SWOT analysis, MCDM techniques, and Delphi methods.

As can be seen, there has been a lot of research on decision-making for NRE planning; however, there are few studies on the appraisal of dissemination or development programs for NRE sources. Haas [16] reviewed market deployment strategies for the broader dissemination of grid-connected PV systems. Monroy and Hernández [17] analyzed the results of a survey of experts and suggested that the possibility of opportunities to innovate in the financing of agricultural electrification projects with renewable sources in developing countries. In this study, the factors and hierarchy for appraising a dissemination program or project were established, and the weights of each factor were calculated using a fuzzy AHP.

This paper is organized as follows. The first chapter on Methods introduces the fuzzy AHP method, the established criteria and factors are described in the Establishing Criteria and Factors chapter, the calculation results of each factor are arranged in the Results chapter, and the four policy implications derived from these results are described in Section 5.

2. Methods

2.1. Literature review on the fuzzy AHP

The AHP has been broadly used in MCDM research. In the AHP, the calculation method proposed by Saaty [18] was based on crisp judgment. However, in the real world, it is very difficult to extract precise data pertaining to measurement factors since all human preferences are prone to a degree of uncertainty. Decision-makers are also inclined to favor natural language expressions over exact numbers when assessing criteria and alternatives. For this reason, the fuzzy AHP methods, which effectively resemble human thoughts and perceptions, were systematically studied by various researchers.

Many fuzzy AHP methods have been proposed on the basis of the concepts of the fuzzy set theory and hierarchical structure analysis. van Laarhoven and Pedrycz [19] directly extended Saaty's AHP method with triangular fuzzy numbers (TFNs) and Buckley [20] extended it with trapezoidal fuzzy numbers. Boender et al. [21] adopted a more robust approach to the normalization of the local priorities by modifying van Laarhoven's and Pedrycz's method. Stam et al. [22] explored how recently developed artificial intelligence techniques can be used to determine or approximate the preference ratings in the AHP and introduced two artificial neural network formulations, a modified Hopfield network and a feed-forward neural network, which can be used to assess the preference ratings from the pairwise comparison matrices of the AHP.

Chang [23] introduced a new approach for handling the fuzzy AHP—the use of TFNs for a pairwise comparison scale of the fuzzy AHP and the use of the extent analysis method for the synthetic extent values of the pairwise comparisons. Chang's approach is one of the most popular approaches in the fuzzy AHP field. The calculation method applied in our research is also based on Chang's approach. Cheng [24] proposed a new algorithm based on the entropy concept for evaluating naval tactical missile systems using the AHP based on the grade value of the membership function. Weck et al. [25] presented a method to evaluate different production cycle alternatives adding the mathematics of fuzzy logic to the classical AHP in order to treat the precision loss of input data due to early stage decision-making on the integration of product and process design. Deng [26] presented a fuzzy approach for tackling qualitative multicriteria analysis problems in a simple

and straightforward manner. Based on the ideas behind the AHP, Lee et al. [27] introduced the concept of comparison interval and proposed a methodology based on stochastic optimization to achieve global consistency and accommodate the fuzzy nature of the comparison process. Cheng et al. [28] proposed a new method for evaluating weapon systems using the AHP based on the linguistic variable weight method to solve the issues of information loss and decision-making.

Zhu et al. [29] presented a discussion on the extent analysis method proposed by Chang [23] and the applications of the fuzzy AHP. They proved the basic TFN theory of the and improved the formulation for comparing the TFN's size. Chan et al. [30] described an integrated approach for the automatic design of a flexible manufacturing system (FMS) that uses simulation and multi-criteria decision-making techniques. They applied the AHP for the selection of the most suitable design to analyze the output from the FMS simulation models and developed intelligent tools such as expert systems, fuzzy systems, and neural networks for supporting the FMS design process. Leung and Cao [31] proposed a fuzzy consistency definition considering a tolerance deviation to treat the consistency in the fuzzy AHP. Essentially, the fuzzy ratios of relative importance, allowing certain tolerance deviation, are formulated as constraints on the membership values of the local priorities.

Bozdağ et al. [32] implemented four different fuzzy multi-attribute group decision-making methods (Blin's model, fuzzy synthetic evaluation, Yager's weighted goals method, and the fuzzy AHP) to select the best computer-integrated manufacturing system, taking into account both intangible and tangible factors. Kahraman et al. [33] applied the same four fuzzy multi-attribute group decision-making methods used in Bozdağ et al. [32] to a facility location selection problem. Kahraman et al. [34] also implemented Chang's [23] method to create an analytical tool that could select the best catering firm providing the most customer satisfaction. Sheu [35] presented a hybrid fuzzy-based method that integrates the fuzzy-AHP and fuzzy-MADM approaches for identifying global logistics strategies. Kulak and Kahraman [36] used both multi-attribute axiomatic design and Chang's [23] method to select the best company as per pre-determined criteria such as cost, time, damage/loss, flexibility, and documentation ability.

Büyüközkan et al. [37] proposed a methodology to improve the quality of decision-making in a software development project under uncertain conditions using a fuzzy present worth method and the fuzzy AHP based on the discussions of Chang [23] and Zhu et al. [29]. Wang and Elhag [38] presented the correct normalization methods for interval and fuzzy weights and offered relevant theorems in their support. Wang et al. [39] revisited the fuzzy logarithmic least squares method (LLSM) in the AHP, pointed out its incorrectness, and suggested a modified fuzzy LLSM to tackle the problems of the previous method. On the basis of Chang's [23] method, Bozbura et al. [40] defined a methodology to improve the quality of the prioritization of human capital measurement indicators under fuzziness. Chan and Kumar [41] identified and discussed some of the important and critical decision-making criteria including risk factors for the development of an efficient global supplier selection system. They applied the fuzzy AHP method based on Chang [23] to tackle different decision-making criteria such as cost, quality, service performance, and supplier's profile.

Recently, Kayakutlu and Büyüközkan [42] demonstrated divergence in the value of the knowledge resources for different role players. They used an integrated Delphi and fuzzy AHP-based framework to help prioritize the balancing factors according to the different role players. Wang et al. [43] criticized Chang's [23] method. According to them, the method could not estimate the true weights from a fuzzy comparison matrix and has led to a number of misapplications as compared to the modified fuzzy LLSM method. Celik et al. [44] structured a practical decision-support mechanism to ensure the multiple criteria analysis of shipping registry selection using the fuzzy AHP methodology based on Chang's [23] method. Güngör et al. [45] proposed a personnel selection system based on the fuzzy AHP and compared the results obtained with those produced by Yager's weighted goals method. They also introduced a practical computer-based decision-support system to provide more information and help managers make better decisions under fuzzy circumstances. Lee et al. [44] briefly introduced a wind farm and developed its critical success criteria. They proposed an MCDM model based on the fuzzy AHP associated with benefits, opportunities, costs, and risks to help select a suitable wind farm project.

As seen in past research, Chang's [23] extent analysis method is one of the most popular and preferred methods in the fuzzy AHP field since the steps involved in this approach are relatively easier than those in the other fuzzy-AHP approaches and similar to those in the conventional AHP. In this study, a slightly modified version of Chang's method was applied, reflecting the discussions of Zhu et al. [29] and Wang and Elhag [38].

2.2. Modified extent analysis method of the fuzzy AHP

The following are the outlines of the extent analysis method of fuzzy AHP:

Let $X = \{x_1, x_2, \ldots, x_n\}$ be an object set and $U = \{u_1, u_2, \ldots, u_m\}$ be a goal set. According to Chang's [23] extent analysis, each object is considered and an extent analysis for each goal, g_i, is performed individually. Therefore, m – the extent analysis value for each object – can be obtained with the following signs:

$$M_{g_i}^1, M_{g_i}^2, \ldots, M_{g_i}^m, \quad i = 1, 2, \ldots, n, \tag{1}$$

where all the $M_{g_i}^j$ $(j = 1, 2, \ldots, m)$ are TFNs whose parameters are a, b, and c. These parameters are of the least possible value, the most possible value, and the highest possible value, respectively. A TFN is represented as (a, b, c). The value of a fuzzy synthetic extent with respect to the $_{jth}$ object is defined as follows:

$$S_i = \sum_{j=1}^{m} M_{g_i}^j \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^j \right]^{-1} \tag{2}$$

According to Wang and Elhag [38], the normalization formula on the synthetic extent is defined as follows:

$$\tilde{S}_i = \left(\frac{\sum a_{ij}}{\sum a_{ij} + \sum\sum c_{kj}}, \frac{\sum b_{ij}}{\sum\sum b_{kj}}, \frac{\sum c_{ij}}{\sum c_{ij} + \sum\sum a_{ij}} \right) \tag{3}$$

The degree of possibility of $M_2 = (a_2, b_2, c_2) \geq M_1 = (a_1, b_1, c_1)$ is defined as follows:

$$V(M_2 \geq M_1) = \sup_{y \geq x} [\min(\mu_{M_1}(x), \mu_{M_2}(y))] \tag{4}$$

and can be equivalently expressed as follows:

$$V(M_2 \geq M_1) = \mathrm{hgt}(M_2 \cap M_1) = \mu_{M_2}(d) = \begin{cases} 1, & \text{if } b_2 \geq b_1 \\ \dfrac{a_1 - c_2}{(b_2 - c_2) - (b_1 - a_1)}, & \text{otherwise} \\ 0, & \text{if } a_1 \geq c_2 \end{cases} \tag{5}$$

where d is the ordinate of the highest intersection point D between μ_{M_1} and μ_{M_2}. To compare M_1 and M_2, we need both the values of $V(M_1 \geq M_2)$ and $V(M_2 \geq M_1)$. The degree of possibility for a convex fuzzy number to be greater than k convex fuzzy numbers

Table 1
Triangular fuzzy conversion scale.

Linguistic scale	Triangular fuzzy scale
Equally important	(1,1,1)
Weakly important	(4/7,1,7/4)
Strongly more important	(5/4,2,11/4)
Very strongly more important	(9/4,3,15/4)
Absolutely more important	(13/4,4,19/4)

$M_i = (i = 1, 2 \ldots, k)$ can be defined by the following:

$$V(M \geq M_1, M_2, \ldots, M_k) = V[(M \geq M_1) \text{ and } (M \geq M_2) \text{ and } \ldots \text{ and } (M \geq M_k)] = \min V(M \geq M_i), \quad i = 1, 2, 3, \ldots, k \tag{6}$$

Assume that $d'(A_i) = \min V(\tilde{S}_i \geq \tilde{S}_k)$, for $k = 1, 2, \ldots, n; k \neq i$. Then the weight vector is given by the following:

$$W' = (d'(A_1), d'(A_2), \ldots, d'(A_n))^T \tag{7}$$

where $A_i = (i = 1, 2 \ldots, n)$ are n elements. Via normalization, the normalized weight vectors are as follows:

$$W = (d(A_1), d(A_2), \ldots, d(A_n))^T \tag{8}$$

where W is a non-fuzzy number. The triangular fuzzy conversion scale based on Zhu et al.'s [29] discussion given in Table 1 was used in the evaluation model of this paper.

3. Establishing criteria and factors

3.1. How to establish the criteria and factors

To establish the criteria and factors, we first reviewed the papers and factors for evaluating the value of the technologies. A draft of the criteria and factors was made on the basis of Becalli et al. [4], Xiaohua and Zhenmin [5], Becalli et al. [46], Aras et al. [6], Nigim et al. [7], Arán Carrión et al. [12], Chatzimouratidis and Pilavachi [47], Terrados et al. [15], and a checklist for technology, market, and firm valuation [48]. The draft was then reviewed by experts.

The first group of experts was a group of policy makers who were members of government (Ministry of Knowledge Economy), government-funded institutes (Korea Energy Management Corporation, Korea Institute of Energy Technology Evaluation and Planning, Korea Energy Economics Institute, and Korea Institute of Energy Research), and a university (Seoul National University). The second group, the specialist group, consisted of members of universities (Korea Maritime University, Yonsei University, Inha University, and so on), civic groups (Consumers Korea, Korean Federation for Environmental Movement, and so on), National RD&D Organizations (National RD&D Organization for Hydrogen and Fuel Cell, Solar Power, Wind Power, and so on), government-funded institutes (Korea Ocean Research and Development Institute, Korea Electrotechnology Research Institute, Korea Institute of Energy Research, and so on), and the Korea New Renewable Energy Association.

The draft was reviewed from June to July 2008. The response rate was 56.8% with 21 experts responding from among the total of 37 experts. The final criteria and factors that were established reflecting the review results are presented in Table 2.

3.2. Description of each factor

Five criteria were selected: technological, market-related, economic, environmental, and policy-related. The description of each factor is as follows:

Table 2
Criteria and factors for dissemination program.

Criteria	Factors
A. Technological	A1. Superiority of technology A2. Completeness of technology A3. Reliability of technology and operation A4. Possibility of acquiring original technology
B. Market	B1. Domestic market size and competitiveness B2. Global market size and competitiveness B3. Competitive power of domestic technology
C. Economic	C1. Supply capability C2. Economic feasibility C3. Supply durability
D. Environmental	D1. Reduction of greenhouse gas and pollutants D2. Requirement of resources D3. Acceptability of local residents
E. Policy	E1. Contribution to achieve dissemination goal E2. Spillover effect E3. Linkage with R&D program E4. Influence of existing social system

- Superiority of technology

  Is the energy supply technology innovative? Does applied technology hardly imitated by competitors such that it has a monopolistic status? Is there a high possibility for it to become an international standard technology?
- Completeness of technology

  Has the core energy supply technology already been developed? Is there any possibility that the applied technology could be substituted with another core technology soon?
- Reliability of technology and operation

  Is the performance of the energy supply technology consistent and replicable under expectable circumstances? Is the frequency of mal-operation of the system low?
- Possibility of acquiring original technology

  Considering the level of the domestic technology, is it easy to acquire the original technology that is the foundation of the energy supply technology?
- Domestic market size and competitiveness

  Is the domestic market size large enough and its demand stable? Is the domestic market in which the selected program is involved competitive?
- Global market size and competitiveness

  Is the global market size large enough and its demand stable? Is the global market in which the selected program is involved competitive? Could the selected program be a Clean Development Mechanism project?
- Competitive power of domestic technology

  Does the domestic technology applied in the selected program have competitive power in the global market? Could the localization rate of the applied technology be higher in the near future?
- Supply capability

  Is the (international) industrial base for energy supply via the selected program rigid? Are the raw materials required for the equipment used in the program abundant enough to meet the demand shock?
- Economic feasibility

  Is the selected program economically feasible? Is a subsidy from the government essential? Is the supply cost of the selected program influenced by other conventional energy prices?

- Supply durability

  Does energy supply via the selected program continue for a considerable period? Could enterprises that are participating in the program last in the market?
- Reduction of greenhouse gas and pollutants

  Is the reduction of greenhouse gas ($grCO_2/MJ$) and pollutants (VOC, SOx, NOx, PM, and so on) via the selected program substantial enough?
- Requirement of resources

  Is the requirement of resources (land, water, air, and so on) needed to proceed with the program high?
- Acceptability of local residents

  Is the selected program easily acceptable to local residents? Is it preferred by local residents? Could the program be adjusted to improve this acceptability or preference?
- Contribution to achieve dissemination goal

  Could the selected program make a substantial contribution to achieve the domestic dissemination goal?
- Spillover effect

  Is the spillover effect (industrial spillover effect, human resource development effect, and so on) of the selected program remarkable?
- Linkage with R&D program

  Could the selected program exist in synergy with the R&D program? Are there any conflicts between the dissemination and the R&D programs?
- Influence of existing social system

  Would the performance of the selected program be sensitively influenced if the existing social system were to be changed?

With the abovementioned criteria and factors, a survey for calculating the weights of each factor was implemented among the same group of experts. The second survey was conducted from August to September 2008 and 25 experts responded among a total of 34 (three had refused to respond in the first review survey), so the response rate was 73.5%. The results of the calculation are presented in the next chapter.

4. Results

4.1. Results of local priorities

The consistency of responses was first checked using the Consistency Ratio (CR) proposed by Saaty [18]. The distribution of the CR calculation results is shown in Fig. 1. Of the total 25 responses, six had a CR higher than 0.15, and these were excluded from our study. The policy maker group consisted of nine members while the specialist group consisted of ten. The estimated weights of five criteria (parent level) are shown in Fig. 2.

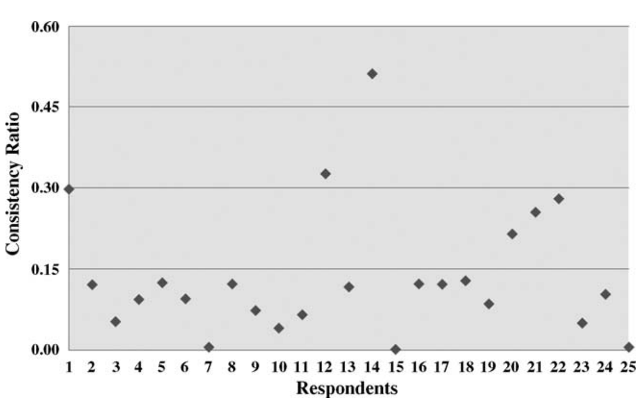

Fig. 1. Distribution of CR.

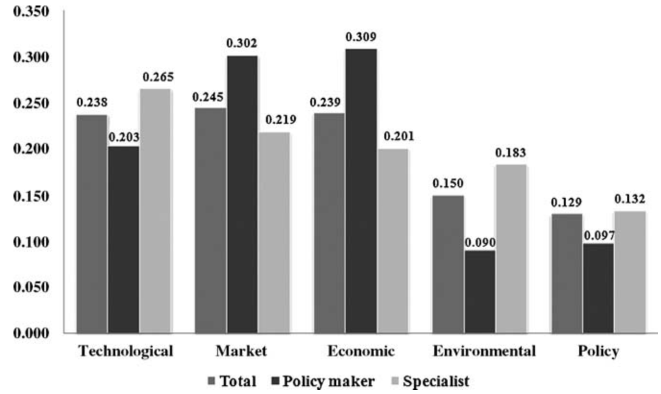

Fig. 2. Estimated weights of five criteria.

Both groups, but especially the policy maker group, estimated that the importance of the environmental and policy criteria was relatively low. The policy maker group assessed the importance of economic and market criteria as high, while the technological criterion was estimated to have the highest weight in the specialist group. The calculation results of the weights of each factor (sibling level) are presented in Table 3.

Regarding the technological criterion, the possibility of acquiring original technology was analyzed as having the highest importance in the policy maker group, and the reliability of technology and operation was estimated to have the highest importance in the specialist group. The policy maker group estimated the weight of the superiority of technology and completeness of technology as almost the same low level; on the other hand, the specialist group estimated the possibility of acquiring original technology to have the least importance.

Next, regarding the market criterion, the policy maker group appraised the competitive power of domestic technology as having the highest importance and the specialist group appraised the global market size, competitiveness, and the competitive power of domestic technology to have almost the same high importance. In other words, both groups believed that the global market is more important than the domestic market. The deviation among the weights was smaller in the policy maker group than in the specialist group.

Table 3
The results of the weights of each factor.

Factors	Total	Policy maker	Specialist
Superiority of technology	0.235	0.201	0.246
Completeness of technology	0.247	0.202	0.270
Reliability of technology and operation	0.276	0.232	0.310
Possibility of acquiring original technology	0.242	0.364	0.174
Domestic market size and competitiveness	0.239	0.285	0.176
Global market size and competitiveness	0.373	0.346	0.412
Competitive power of domestic technology	0.388	0.369	0.411
Supply capability	0.311	0.268	0.351
Economic feasibility	0.420	0.448	0.392
Supply durability	0.269	0.284	0.258
Reduction of greenhouse gas and pollutants	0.562	0.465	0.665
Requirement of resources	0.210	0.253	0.157
Acceptability of local residents	0.229	0.282	0.177
Contribution to achieve dissemination goal	0.414	0.458	0.377
Spillover effect	0.179	0.158	0.194
Linkage with R&D program	0.294	0.327	0.267
Influence of existing social system	0.114	0.058	0.161

Table 4
The results of global priorities.

Factors	Total	Policy maker	Specialist	Differences
C2	0.101	0.138	0.079	0.060
B3	0.095	0.111	0.090	0.021
B2	0.091	0.104	0.090	0.014
D1	0.084	0.042	0.122	0.080
C1	0.075	0.083	0.070	0.012
A3	0.066	0.047	0.082	0.035
C3	0.064	0.088	0.052	0.036
A2	0.059	0.041	0.072	0.031
B1	0.059	0.086	0.039	0.047
A4	0.057	0.074	0.046	0.028
A1	0.056	0.041	0.065	0.024
E1	0.053	0.045	0.050	0.005
E3	0.038	0.032	0.035	0.004
D3	0.034	0.025	0.032	0.007
D2	0.031	0.023	0.029	0.006
E2	0.023	0.015	0.026	0.010
E4	0.015	0.006	0.021	0.016

Regarding the economic criterion, economic feasibility was estimated to be the most important factor in both groups. After this, supply capability was estimated as being the second most important in the specialist group. The policy maker group estimated that the difference of supply capability and durability was only about 6%.

Regarding the environmental criterion, the ranking of the weights was estimated in the order of reduction of greenhouse gas and pollutants, acceptability of local residents, and requirement of resources. However, the specialist group appraised the weight of the reduction of greenhouse gas and pollutants at about 40% higher than that of the policy maker group.

Next, regarding the policy criterion, like the environmental criterion, the weights estimated were ranked in the same order in both groups – in the order of contribution – to achieve the dissemination goal, linkage with the R&D program, the spillover effect, and the influence of the existing social system. However, the policy maker group appraised the weight of the contribution to achieve the dissemination goal at approximately 20% higher than the specialist group.

4.2. Results of global priorities

The results of global priorities calculated by multiplying the weights of the criteria (parents) to the weights of each factor (siblings) are presented in Table 4.

Economic feasibility was estimated to have the highest weight among all the factors in the calculation of the total respondents (the highest in the policy maker group and the fifth rank in the specialist group). The factor that had the second highest weight in total was the competitive power of domestic technology (the second highest in the policy maker group and a tie for the second place in the specialist group). Global market size and competitiveness ranked third in total and tied for second place in the policy maker and specialist groups. The reduction of greenhouse gas and pollutants, which was estimated to have the second highest importance in the specialist group was ranked eighth in the policy maker group. It was interesting that the first, second, and third weight rankings of the total respondents were the same as those in the policy maker group.

5. Conclusions

We established five criteria (technological, market-related, economic, environmental, and policy-related) and a total of seventeen factors using fussy AHP in order to formulate an effective dissemination program and appraise it. Four conclusions can be derived from the factor-weights estimation results.

First, economic feasibility was analyzed to be the most important among all the factors. Up until now, the Korean government has operated dissemination programs for every renewable energy types, and focused only on supply side stimulations. However, in the 3rd Basic Plan, the dissemination paradigm has shifted toward the demand side stimulation and integration of programs across energy types. In addition, the government will introduce a renewable portfolio standard (RPS) system in 2012 so that the competition level will escalate among NRE sources. Consequently, economic feasibility will be more important when establishing a dissemination program.

Second, the global market size and global competitive power of domestic technology is of critical importance because the Korean renewable energy market size is limited. This is also true for other countries except a few that have a large domestic renewable energy market. Therefore, based on the performance of the domestic market, the advancement of the target technology in the global market must be considered when establishing an renewable energy dissemination program.

Third, there were significant differences between the estimated weights derived from the policy maker and the ones from the specialist group. The most disparate factor was the influence of the existing social system. The specialist group estimated that factor to be approximately 3.8 times (0.015 difference in real weight level) more important than the policy maker group. In addition, the specialist group estimated the reduction of greenhouse gas and pollutants to be about 2.9 times (0.08 difference in real weight level) more important than the policy maker group did. On the other hand, the policy maker group assessed the domestic market size and competitiveness to be approximately 2.2 times (0.047 difference in real weight level) more important than the specialist group did. Economic feasibility, reliability of technology and operation, completeness of technology, and supply durability were analyzed to have a relatively large disagreement. The factors with less than 20% disagreement were merely related to the R&D program (11.4%), contribution to achieve dissemination goal (12.1%), global market size and competitiveness (15.8%), and supply capability (17.6%). These differences indicate the existence of a significant gap in the ways of approaching dissemination programs between researchers and policy makers as renewable energy programs are in the early stage in Korea.

Fourth, the weights derived in this study can be applied to both establishing (ex-ante) and appraising (ex-post) stages of renewable energy dissemination programs. The factors and weights derived from this paper will help policy and decision-makers to establish an effective dissemination programs and also appraise and improve them.

Acknowledgement

This research was supported by Research Center for New & Renewable Energy Policy Program by Ministry of Knowledge Economy.

References

[1] IEA. World energy outlook 2008 (executive summary). Paris: IEA; 2008.
[2] BP. BP statistical review of world energy June 2009. London: BP p.l.c.; 2009.
[3] KEMCO. New and renewable energy statistics 2007, 2008 ed., Yongin, Korea: KEMCO; 2008.
[4] Beccali M, Cellura M, Ardente D. Decision making in energy planning: the ELECTRE multicriteria analysis approach compared to a FUZZY-SETS methodology. Energy Conversion and Management 1998;39:1869–81.
[5] Xiaohua W, Zhenmin F. Sustainable development of rural energy and its appraising system in China. Renewable and Sustainable Energy Reviews 2002;6:395–404.
[6] Aras H, Erdoğmuş Ş Koç E. Multi-criteria selection for a wind observation station location using analytic hierarchy process. Renewable Energy 2004;29: 1383–92.

[7] Nigim K, Munier N, Green J. Pre-feasibility MCDM tools to aid communities in prioritizing local viable renewable energy sources. Renewable Energy 2004;29:1775–91.
[8] Pohekar SD, Ramachandran M. Application of multi-criteria decision making to sustainable energy planning—a review. Renewable and Sustainable Energy Reviews 2004;8:365–81.
[9] Erdoğmuş Ş Aras H, Koç E. Evaluation of alternative fuels for residential heating in Turkey using analytic network process (ANP) with group decision-making. Renewable and Sustainable Energy Reviews 2006;10:269–79.
[10] Løken E. Use of multicriteria decision analysis methods for energy planning problems. Renewable and Sustainable Energy Reviews 2007;11:1584–95.
[11] Jaber JO, Jaber QM, Sawalha SA, Mohsen MS. Evaluation of conventional and renewable energy sources for space heating in the household sector. Renewable and Sustainable Energy Reviews 2008;12:278–89.
[12] Arán Carrión J, Espín Estrella A, Aznar Dols F, Zamorano Toro M, Rodríguez M, Ramos Ridao A. Environmental decision-support systems for evaluating the carrying capacity of land areas: optimal site selection for grid-connected photovoltaic power plants. Renewable and Sustainable Energy Reviews 2008;12:2358–80.
[13] Mirza UK, Ahmad N, Harijan K, Majeed T. Identifying and addressing barriers to renewable energy development in Pakistan. Renewable and Sustainable Energy Reviews 2009;13:927–31.
[14] Lee AHI, Chen HH, Kang H-Y. Multi-criteria decision making on strategic selection of wind farms. Renewable Energy 2009;34:120–6.
[15] Terrados J, Almonacid G, Perez-Higueras P. Proposal for a combined methodology for renewable energy planning. Application to a Spanish region Renewable and Sustainable Energy Reviews; 2009;13:2022–30.
[16] Haas R. Market deployment strategies for photovoltaics: an international review. Renewable and Sustainable Energy Reviews 2003;7:271–315.
[17] Monroy CR, Hernández ASS. Strengthening financial innovation in energy supply projects for rural exploitations in developing countries. Renewable and Sustainable Energy Reviews 2008;12:1928–43.
[18] Saaty TL. The analytic hierarchy process: planning, priority setting, resource allocation. New York/London: McGraw-Hill International Book Co.; 1980.
[19] van Laarhoven PJM, Pedrycz W. A fuzzy extension of Saaty's priority theory. Fuzzy Sets and Systems 1983;11:199–227.
[20] Buckley JJ. Fuzzy hierarchical analysis. Fuzzy Sets and Systems 1985;17:233–47.
[21] Boender CGE, Graan JGd, Lootsma FA. Multicriteria decision analysis with fuzzy pairwise comparisons. Fuzzy Sets Systems 1989;29:133–43.
[22] Stam A, Sun M, Haines M. Artificial neural network representations for hierarchical preference structures. Computers & Operations Research 1996;23:1191–201.
[23] Chang D-Y. Applications of the extent analysis method on fuzzy AHP. European Journal of Operational Research 1996;95:649–55.
[24] Cheng C-H. Evaluating naval tactical missile systems by fuzzy AHP based on the grade value of membership function. European Journal of Operational Research 1996;96:343–50.
[25] Weck M, Klocke F, Schell H, Ruenauver E. Evaluating alternative production cycles using the extended fuzzy AHP method. European Journal of Operational Research 1997;100:351–66.
[26] Deng H. Multicriteria analysis with fuzzy pairwise comparison. International Journal of Approximate Reasoning 1999;21:215–31.
[27] Lee M, Pham H, Zhang X. A methodology for priority setting with application to software development process. European Journal of Operational Research 1999;118:375–89.
[28] Cheng C-H, Yang K-L, Hwang C-L. Evaluating attack helicopters by AHP based on linguistic variable weight. European Journal of Operational Research 1999;116:423–35.
[29] Zhu K-J, Jing Y, Chang D-Y. A discussion on extent analysis method and applications of fuzzy AHP. European Journal of Operational Research 1999;116:450–6.
[30] Chan FTS, Jiang B, Tang NKH. The development of intelligent decision support tools to aid the design of flexible manufacturing systems. International Journal of Production Economics 2000;65:73–84.
[31] Leung LC, Cao D. On consistency and ranking of alternatives in fuzzy AHP. European Journal of Operational Research 2000;124:102–13.
[32] Bozdağ CE, Kahraman C, Ruan D. Fuzzy group decision making for selection among computer integrated manufacturing systems. Computers in Industry 2003;51:13–29.
[33] Kahraman C, Ruan D, Doğan I. Fuzzy group decision-making for facility location selection. Information Sciences 2003;157:135–53.
[34] Kahraman C, Cebeci U, Ruan D. Multi-attribute comparison of catering service companies using fuzzy AHP: the case of Turkey. International Journal of Production Economics 2004;87:171–84.
[35] Sheu J-B. A hybrid fuzzy-based approach for identifying global logistics strategies. Transportation Research Part E Logistics and Transportation Review 2004;40:39–61.
[36] Kulak O, Kahraman C. Fuzzy multi-attribute selection among transportation companies using axiomatic design and analytic hierarchy process. Information Sciences 2005;170:191–210.
[37] Büyüközkan G, Kahraman C, Ruan D. A fuzzy multi-criteria decision approach for software development strategy selection. International Journal of General Systems 2004;33:259–80.
[38] Wang Y-M, Elhag TMS. On the normalization of interval and fuzzy weights. Fuzzy Sets and Systems 2006;157:2456–71.
[39] Wang Y-M, Elhag TMS, Hua Z. A modified fuzzy logarithmic least squares method for fuzzy analytic hierarchy process. Fuzzy Sets and Systems 2006;157:3055–71.
[40] Bozbura FT, Beskese A, Kahraman C. Prioritization of human capital measurement indicators using fuzzy AHP. Expert Systems with Applications 2007;32:1100–12.
[41] Chan FTS, Kumar N. Global supplier development considering risk factors using fuzzy extended AHP-based approach. Omega 2007;35:417–31.
[42] Kayakutlu G, Büyüközkan G. Assessing knowledge-based resources in a utility company: identify and prioritise the balancing factors. Energy 2008;33:1027–37.
[43] Wang Y-M, Luo Y, Hua Z. On the extent analysis method for fuzzy AHP and its applications. European Journal of Operational Research 2008;186:735–47.
[44] Celik M, Deha Er I, Ozok AF. Application of fuzzy extended AHP methodology on shipping registry selection: the case of Turkish maritime industry. Expert Systems with Applications 2009;36:190–8.
[45] Güngör Z, Serhadlıoğlu G, Kesen SE. A fuzzy AHP approach to personnel selection problem. Applied Soft Computing 2009;9:641–6.
[46] Beccali M, Cellura M, Mistretta M. Decision-making in energy planning. Application of the Electre method at regional level for the diffusion of renewable energy technology. Renewable Energy 2003;28:2063–87.
[47] Chatzimouratidis AI, Pilavachi PA. Multicriteria evaluation of power plants impact on the living standard using the analytic hierarchy process. Energy Policy 2008;36:1074–89.
[48] Seol SS, Lee KH. A study on checklist for technology, market and firm analysis. Journal of Korea Technology Innovation Society 2002;5:277–92 [in Korean].